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## Article

# How Much Time Does a Farmer Spend to Produce My food? An International Comparison of the Impact of Diets and Mechanization

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**Abstract:** Work is one of the main inputs in agriculture. It can be performed by humans, animals, or machinery. Studies have shown strong differences throughout the world in labour required to produce a kilogram of food. We complement this line of research by linking these data to food consumption patterns, which are also strongly different throughout the world. We calculate the hours of farm labour required to produce a person's annual food consumption for four scenarios. These scenarios are comprised of two extreme cases for production systems and diets, respectively, that illustrate prevailing global differences. Our results show that the farm labour requirements differ by a factor of about 200 among production systems, and by a factor of about two among consumption patterns. The gain in farm labour efficiency with mechanization is enormous: only 2–5 hours of farm labour are needed to produce the food consumed by a person in a year. This value is much lower than the time an average person spends on buying food, cooking, or eating.

**Keywords:** farm labour; agricultural production systems; international comparison; food consumption patterns

## 1. Introduction

In order to produce agricultural products, a piece of land is needed to plant the crops, nutrients, and water are needed to let them grow, and work is needed to plant, manage, and harvest them. These are the main agricultural inputs: land, water, nutrients, and work. Work can be either human labour, delivered by livestock, or by machinery. Pimentel and Pimentel [1] analyse and compare the use of agricultural inputs among global extremes of agricultural production systems. They cover extensive systems with almost no external energy inputs (such as machinery and fertilizers) to intensive, highly-mechanized systems. Pimentel and Pimentel [1] show strong differences in human labour requirements per kilogram of crop produced because of the replacement of human labour with machinery in highly-mechanized systems. In this paper, we build on this analysis by linking food consumption patterns with farm labour inputs of contrasting production systems.

By doing so, we complement a line of research that has emerged in the last years, studying the impact of both production and consumption of food on the use of agricultural resources, such as land [2], water [3], and nitrogen [4–6]. These studies show the impact of diets on the agricultural resource requirements and typically show how many resources are needed to produce the food

consumed by one person in a year. The food in the diet is traced back to the agricultural production in order to link it with the amount of resources that were used to produce it.

The studies have shown that, in general, affluent diets require larger amounts of agricultural resources than basic diets. However, in some cases, the type of production system can overrule the type of diet. For example, the very basic diet of Middle Africa, relying largely on staple crops, requires a similar amount of arable land than the very affluent consumption patterns of Western Europe [2]. The reason is that the food of Middle Africa is produced in low crop yields systems and the food of Western Europe is produced in high crop yield systems. The methodology of these studies make it possible to combine both the differences in production and in diets throughout the world to assess the impact on the use of agricultural resources.

In this paper, we focus on analysing how farm labour requirements for the food consumed by one person changes as farming intensifies and diets become more affluent. Large global differences exist among food production systems in relation to labour requirements. The whole spectrum covers from low input systems, relying exclusively on labour by hand or by draft animals, to high-input systems where the production is highly mechanized [1]. Additionally, diets differ greatly throughout the world in respect the consumption of staple and affluent food products [7]. In order to provide an international comparison of the farm labour for food, we select four different scenarios representing the global extremes of diets and production systems. Our main research question is: How much farm labour is needed for the production of our food consumption, and what is the role of dietary patterns in the observed differences? Answering this question will give insights into, for instance, what extent the effect of mechanization decreasing farm labour demand is potentially offset by more resource-intensive diets.

## 2. Materials and Methods

Studies on the use of agricultural resources for food [2,3,5,6] often combine food consumption data (in kg/cap/year) with food production data (resources/kg food) to calculate the resource use per capita. In this paper, we follow a similar methodology in which the production data is the hours of farm labour needed to produce a kilogram of food. Thus, we define the *farm labour for food* as the amount of human working hours needed in agriculture (crops and livestock) to produce the food that a person consumes in a year. The starting point is the food consumed per capita, which is linked to the agricultural labour required to produce the given amount of food.

We included labour for production up to the farm gate, i.e., planting, harvesting, weeding, and livestock management. The data was gathered from different sources that calculate all of the human labour required for each crop and livestock product at the farm scale (see Tables 1–3). We calculated the farm labour for food for four scenarios. Each of the four scenarios is a combination of a production system and a diet to illustrate the global differences of consumption and production of food. Scenario 1 represents an affluent diet produced in a non-mechanized system, scenario 2 an affluent diet produced in a mechanized system, scenario 3 a basic diet produced in a non-mechanized system, and scenario 4 a basic diet produced in a mechanized system.

The average per capita food supply of Western Europe in 2010 was used for the affluent diet scenario, and the one of Middle Africa in 2010 was used as the basic diet. The food consumption data were gathered from the FAO statistics [11]. The FAO [11] gives food supply data for 92 food items. In order to identify the impact of the production and consumption data in the farm labour for food, simplification of the diet is needed. We grouped these food items into 12 categories, the food items in each food category have comparable agricultural labour requirements. The food categories are: cereals, roots, pulses, vegetable oils, vegetables, fruits, alcoholic beverages, milk, eggs, beef, pork, and chicken. Sugars are not included in the calculations since no data was available for the production of sugar crops in non-mechanized systems. Stimulants, such as coffee, tea, and cocoa are not included in the farm labour for food, but it is discussed in Section 3.4.

**Table 1.** Data source of crop production systems; the corresponding values are presented in Table 4.

Food Category	Production System	Crop	Country and Area	Source
Cereal	Mechanized	Wheat	USA	Pimentel and Pimentel [1]
Cereal	Non-mechanized	Wheat	India, valley	Tripathi and Sah [8]
Roots	Mechanized	Potatoes	USA	Pimentel [9]
Roots	Non-mechanized	Potatoes	India, valley	Tripathi and Sah [8]
Pulses	Mechanized	Dry Bean	USA	Pimentel and Pimentel [1]
Pulses	Non-mechanized	Lentil	India, valley	Tripathi and Sah [8]
Oil crop	Mechanized	Soybeans	USA	Pimentel and Pimentel [1]
Oil crop	Non-mechanized	Soybeans	India, mid-hill	Tripathi and Sah [8]
Vegetables	Mechanized	Cabbages	USA	Pimentel and Pimentel [1]
Vegetables	Non-mechanized	Cabbages	India, high-hill	Tripathi and Sah [8]
Fruits	Mechanized	Apples	USA	Pimentel and Pimentel [1]
Fruits	Non-mechanized	Apples	India, high-hill	Tripathi and Sah [8]
Cereal for alcoholic beverages	Mechanized	Barley	Iran	Mobtaker et al [10]
Cereal for alcoholic beverages	Non-mechanized	Barley	India, valley	Tripathi and Sah [8]
Feed	Mechanized	Maize	USA	Pimentel [9]
Feed	Non-mechanized	Maize	Mexico	Pimentel and Pimentel [1]

The data sources of the production data of the vegetable products are indicated in Table 1. The underlying studies quantify the amount of labour (in hours or days) in the agricultural field to produce a certain amount of crop, and indicate the obtained crop yields. The labour hours for the vegetable products produced in non-mechanized systems was gathered from [8]. The data is given in days of work per hectare, we assumed that each working day includes 8 hours. By combining these data, we calculated the required hours of farm labour per kg of crop (see Equation (1)). Each food category of the diet is represented by one crop. In addition to human labour, the mechanized system uses mainly machinery for all of the tasks: ploughing, planting, weeding, and harvesting. The non-mechanized system uses draft animal power mainly for ploughing, and the rest is done only by human labour.

The following equations summarize our approach to calculate the hours of farm labour for food. The underlying values are presented in Tables 2 and 4.

For vegetable products:

$$\text{Farm labour for food} \left[ \frac{\text{hrs}}{\frac{\text{cap}}{\text{year}}} \right] = \frac{\text{Labour} \left[ \frac{\text{hrs}}{\text{ha}} \right]}{\text{Crop yield} \left[ \frac{\text{kg}}{\text{ha}} \right]} \times \text{food consumption} \left[ \frac{\text{kg}}{\frac{\text{cap}}{\text{year}}} \right] \quad (1)$$

For animal products:

$$\begin{aligned} \text{farm labour for food} \left[ \frac{\text{hrs}}{\frac{\text{cap}}{\text{year}}} \right] &= \left[ \text{Animal management} \left[ \frac{\text{hrs}}{\text{kg}} \right] + \text{Labour for feed} \left[ \frac{\text{hrs}}{\text{kg}} \right] \times \text{feed food eff. ratio} \right] \\ &\times \text{food consumption} \left[ \frac{\text{kg}}{\frac{\text{cap}}{\text{year}}} \right] \end{aligned} \quad (2)$$

The labour needed for the production of the animal products includes: the labour to produce the feed as well as the labour for animal management (see Equation (2)). To calculate the labour to produce the feed, we assumed that one type of crop was used as feed for all the animal products. We selected maize as the feed for both the mechanized and the non-mechanized systems. We then multiplied the hours required to produce one kg of maize by an efficiency factor (Table 2) for each animal product to calculate the hours per kilogram of meat, milk, or eggs (Table 3). The conversion efficiency factors

for livestock products were obtained from [12] (Appendix 1). We used the global average data of an industrial system. For the non-mechanized system, only chicken was produced with off-farm feed (see details below). Therefore, the conversion efficiency factors (Table 2) were used for all animal products of the mechanized systems and for chicken meat of the non-mechanized systems.

**Table 2.** Conversion efficiency factors for livestock products.

Livestock Food	Global Average of Industrial System
Beef	19
Pork	3.9
Chicken	2.8
Eggs	2.3
Milk	1.1

The values are in kilograms of feed (dry mass) per kilogram of output. The output refers to carcass meat, milk, or eggs. Source: [12] (Appendix 1).

**Table 3.** Comparison of livestock production systems: large scale farms vs. smallholders.

Livestock Product	Production System	Animals Places/Farm	Lifespan of Animals (Months)	Kg Food Product/Animal	Country
Beef	Large scale farm	400 <sup>1</sup>	24 <sup>1</sup>	338 <sup>6</sup>	Netherlands
Beef	Smallholder	8 <sup>2</sup>	24 <sup>1</sup>	270 <sup>2,8</sup>	Brazil
Chicken	Large scale farm	90,000 <sup>1</sup>	2 <sup>1</sup>	1.9 <sup>6</sup>	Netherlands
Chicken	Smallholder	17 <sup>3</sup>	2 <sup>1</sup>	1.2 <sup>7</sup>	Zimbabwe
Pork	Large scale farm	4000 <sup>1</sup>	6 <sup>1</sup>	92 <sup>6</sup>	Netherlands
Pork	Smallholder	2 <sup>4</sup>	12 <sup>4</sup>	52 <sup>4,8</sup>	India
Milk	Large scale farm	50 <sup>10</sup>	-	8500/year <sup>1</sup>	Netherlands
Milk	Smallholder	2 <sup>5</sup>	-	721/year <sup>5</sup>	Bangladesh
Eggs	Large scale farm	60,000 <sup>1</sup>	-	22/year <sup>1</sup>	Netherlands
Eggs	Smallholder	17 <sup>3</sup>	-	5/year <sup>9</sup>	Zimbabwe

<sup>1</sup> [13]; <sup>2</sup> [14]; <sup>3</sup> [15]; <sup>4</sup> [16]; <sup>5</sup> [17]; <sup>6</sup> kilograms of meat produced per animal in 2010 for North America [11]; <sup>7</sup> kilograms of meat produced per animal in 2010 for South Asia [11]; <sup>8</sup> dressing factors from [18] (Table 1) cow: 0.6, pig: 0.8, chicken: 0.75; <sup>9</sup> kilograms of eggs per hen per year in 2010 for Zimbabwe [11]; <sup>10</sup> Our own calculation based on annual milk production per farm (425,000 kg) and milk production per cow (8500 kg), with both data from [13].

Large-scale intensive farms were used as examples of the farm labour for livestock maintenance in a mechanized system. Data were obtained from KWIND (Quantitative Information on Livestock Keeping) [13]. This book provides overviews on what is needed to run an average farm in the Netherlands (machinery, livestock feed, labour, investments, energy etc.) for various types of livestock. The data that we used were the number of animal places that a farmer can manage in their farm and the life time of the animals before slaughter (Table 3). We assumed that each farmer works 2000 hours per year. We used data on meat production per animal from the FAO statistics [11], and data on milk and eggs production from KWIND [13]. We combine these data to calculate the hrs/kg of animal product of maintenance labour in the farm (Table 4).

Smallholders livestock systems were used as examples of the farm labour for livestock maintenance in a non-mechanized system. The choice of the production system to illustrate these non-mechanized systems was more difficult than the choice for the mechanized system, which are well documented. Large variety exists in small livestock production systems throughout the world. It is difficult to identify an example of production system for all animal products with the same degree of labour efficiency. We have chosen case studies of smallholders' producers in different parts of the world. The number of hours of labour for livestock production in these systems is not as clear as for the intensive systems because these farmers usually do mix systems of producing other food crops or doing non-agricultural activities to earn extra income. Additionally, the labour is shared within the household and sometimes women's and children's labour are not fully quantified. However,

we have chosen some studies that have calculated, based on surveys and interviews, the amount of labour needed exclusively for the livestock production in smallholder systems. These case studies illustrate a general picture of the labour needed in small scale non-mechanized systems which show large differences in comparison with the large scale mechanized systems (Tables 3 and 4). We briefly describe these studies below.

**Table 4.** Production and consumption data for the four scenarios, which include mechanized system (m), non-mechanized system (n-m), affluent diet (A), and basic diet (B).

Food		Production Data			Consumption Data
Vegetable Products					
Food Category	Crop	Yield (kg/ha)	Labour (hrs/ha)	Labour for kg of Food (hrs/kg)	Food Consumption (kg/cap/year)
Cereals	Wheat (m)	2670	8	0.003	115 (A)
Cereals	Wheat (n-m)	1500	1098	0.7	107 (B)
Roots	Potatoes (m)	40,656	35	0.001	68 (A)
Roots	Potatoes (n-m)	2800	1875	0.7	185 (B)
Pulses	Dry beans (m)	1457	10	0.007	1.5 (A)
Pulses	Lentil (n-m)	300	683	2.3	12 (B)
Veg oils	Soybeans (m)	2668	7	0.003	19 (A)
Veg oils	Soybeans (n-m)	1300	1217	0.9	8 (B)
Vegetables	Cabbages (m)	38,416	60	0.002	100 (A)
Vegetables	Cabbages (n-m)	11,400	1834	0.2	64 (B)
Fruits	Apples (m)	55,000	385	0.007	109 (A)
Fruits	Apples (n-m)	900	230	0.3	74 (B)
Alcoholic	Barley (m)	4800	83	0.017	112 (A)
Beverages	Barley (n-m)	500	960	1.7	54 (B)
Feed	Maize (m)	8655	11	0.001	N.A.
Feed	Maize (n-m)	940	383	0.4	N.A.
Animal Products					
Food	Production System	External Feed Needed	Animal Management Labour in Farm (hrs/kg)	Labour for feed (hrs/kg)	Food Consumption (kg/cap/year)
Beef	Large scale farm (m)	Yes	0.03	0.025	18 (A)
Beef	Smallholder (n-m)	No	1.3	N.A.	7 (B)
Pork	Large scale farm (m)	Yes	0.003	0.005	44 (A)
Pork	Smallholder (n-m)	No	3.5	N.A.	4 (B)
Chicken	Large scale farm (m)	Yes	0.0019	0.004	20 (A)
Chicken	Smallholder (n-m)	Yes	3	1.1	8 (B)
Milk	Large scale farm (m)	Yes	0.005	0.001	260 (A)
Milk	Smallholder (n-m)	No	1.5	N.A.	16 (B)
Eggs	Large scale farm (m)	Yes	0.0015	0.003	13 (A)
Eggs	Smallholder (n-m)	Yes	4.5	0.9	1 (B)

For beef, we used data from smallholders in Eastern Amazon, Brazil [14]. The smallholders have pastures for the cattle in combination with mixed systems of cassava, maize, pepper, and others. The cattle are fed only by pastures; no off-farm feed is used. On average, one farm has 14.7 hectares of pastures for 8.3 cows of 450 kg of life weight each. The labour required is an average 12 days of work per hectare, which includes planting, weeding, fencing, cutting down secondary vegetation, and animal care. We assumed a bull lives two years, and a dressing factor of the bull of 0.6 [18], so each bull produces 270 kg of carcass meat.

For chicken meat and eggs, we used data from smallholders in the semi-arid region of Zimbabwe [15]. These households have a mixed system of maize, cotton, sunflower, and a vegetable garden in addition to the chickens, and some of them also have cattle and small ruminants. The households have in average 17 chicken, and almost all farms supplemented the chicken with feed. Labour for chicken demanded the least time of the household duties and it was carried out all year. Muchadeyi [15] show that, on average, one person spends one hour per day for managing the chickens, including penning the chickens at night, releasing them in the morning, and feeding them. We assumed two systems: one smallholder producing chicken meat and another producing eggs. For the chicken meat, we assumed a lifespan of two months, so each household produced 102 chicken



per year on average, and each chicken produces 1.2 kg of meat (average data for Zimbabwe in 2010 from the FAO [11]). For eggs, we assumed that the 17 chicken are hens that each produce 5 kg of eggs per year (yield data for Zimbabwe in 2010 from the FAO [11]).

For pork, we used data from smallholders in the mountain area of Northeast India [16]. These households also have mixed farming systems. On average, one household has two pigs which are kept in the backyard of the house. Most households practice stall feeding and not scavenging. The household produced the feed by cooking kitchen wastes, crop residues and plants collected from the forest or nearby areas. The pigs are fed twice a day. The live weight at 12 months is in average 65 kg per pig. We assume a dressing factor of 0.8 [18] and after 12 months the pigs are slaughtered, so one pig produces 52 kg of meat per year. Kumaresan et al. [16] do not give a number in the hours of labour needed for these activities, so we assumed one hour per day is needed all year long.

For milk, we used data from small-scale extensive systems in Bangladesh [17]. On average, the households have two cows in a mixed farming system including rice production with 0.5 hectares of land for grazing and also perform off-farm activities. The farmers practice a “cut and carry feeding system” [17] and, in addition to using their own land, they use public land for periodic grazing. Family labour is the only labour involved in managing the cows which involve 2163 hours per year per household, and each cow produces 721 kg of milk [17].

Based on the data described above, we calculated the amount of farm labour needed to produce a kilogram of meat, milk and eggs. The results are shown in Table 4.

After discussing the differences among production systems, we discuss the differences in diets. To do this, we used calories per person per day as the unit of measure, which is commonly used to describe nutritional differences. However, the data on diets that we used to calculate the farm labour for food is in kilograms per person per year. The data in both units (kilograms and kilocalories) were obtained from [11].

Finally, we calculated the farm labour for food by combining the data of production (hrs/kg) and consumption (kg/cap/year) of all food categories to calculate the agricultural hours of labour needed per person (hrs/cap) for the four scenarios (see Equations (1) and (2)). The data is shown in Table 4. The consumption data of vegetable oils and alcoholic beverages was converted into its crop equivalent following the methodology of Kastner and Nonhebel [19]. We assumed that beer provides for the consumption of alcoholic beverages and soybean oil for the consumption of the vegetable oils.

### 3. Results

#### 3.1. Labour Hours Per Kilogram of Food

The mechanized and non-mechanized systems differ widely, in both output per unit of land (crop yield) and labour input per unit of land, so the differences in hours worked per kg of food should be analysed considering both factors. In general, mechanized systems use less hrs/ha and obtain higher crop yields, which result in much lower hrs/kg than the non-mechanized systems. The lower labour per hectare is related to the machinery used in comparison with non-mechanized systems. The higher crop yields are not related to the machinery but with the use of other inputs, such as fertilizers and pesticides.

Differences exist among the type of crops. Potatoes result in the largest difference in hrs/ton: the value for the non-mechanized system is about 800 times the one of the mechanized system. In this case, the hours per hectare are about 50 times higher in the non-mechanized system, and the crop yield is about 15 times higher in the mechanized system. Differing by a factor of 250–350, cereals and oil crops show the largest difference in terms of field labour per unit area. However, for cereals the difference between crop yields is less pronounced with a factor 2. As a result, the difference relative between the systems in hrs/kg is less than the one for potatoes. With a factor of about 100, fruits and vegetables show the smallest difference in terms of farm labour input per unit product comparing the non-mechanized to the mechanized system. The reason is different for each food

categories. For vegetables, the labour in the field (hrs/ha) is relatively different (factor: 30) but the crop yields are very similar. For fruits, both systems show very similar labour in the field (hrs/ha), but the crop yield is very different (factor: 60).

Similar to the vegetable products, the animal products show a strong difference in the hrs/kg between the mechanized and the non-mechanized system. Farm labour requirements in smallholder systems are 600–1500 times those in industrial systems for chicken, pork, milk, and eggs; for beef the factor is lower, with a value of about 50. The large-scale farms have high labour efficiency because of two main reasons. First, a very large number of animals are managed by only one farmer. For chicken and pork, the difference higher than a factor 1000, for beef and milk it is “only” a factor of 50 and 100, respectively (Table 3). Second, the amount of meat or milk produced per animal is larger in industrial systems (Table 3).

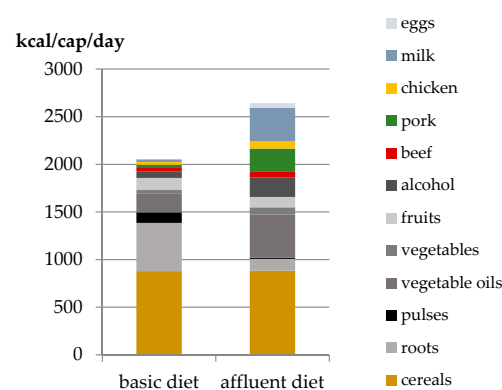
The relation between the farm labour for the feed and for the animal management in the farm is different between the mechanized and non-mechanized system. For the large-scale farms, the labour for the feed (in hrs/kg) is higher than the farm labour for management in the livestock farms. The opposite holds for the smallholder livestock.

The labour efficiency is different in the large-scale farms for the different products. Eggs and chicken require the least farm labour per kilogram produced: 0.0015 hrs/kg and 0.0019 hrs/kg, respectively. Pork (0.003 hrs/kg) and milk (0.005 hrs/kg) follow. Beef is the least labour efficient with 0.03 hrs/kg for two main reasons: first, the lifespan is longer for cattle than for pigs and chicken. Second, the average stock size per farm for cattle is smaller than for pigs and chicken.

The labour efficiency among the animal products in the smallholder system shows a different pattern: eggs are the least efficient followed by pork, chicken, milk, and beef. However, the data for these systems were gathered from different sources, countries, and production systems. Therefore, the difference in hrs/kg among the animal products in the non-mechanized systems may not be due to the type of product but by the type of production system. However, as additional analysis shows, this limitation of the data does not alter our results on the general differences between mechanized and non-mechanized systems (see Supplementary Materials).

### 3.2. Food Consumption Patterns

The basic diet and the affluent diet differ in both the amounts of calories consumed and the composition of the products (Figure 1). The total caloric availability of the affluent diet is 500 kcal/cap/day higher than the one of the basic diet. The largest difference originates from the amount of animal products in the diets. For the affluent diet, 30% of the calories are of animal origin and for the basic diet this value is only 6%. The number of calories for vegetable products is relatively similar, around 1900 kcal/dap/day each. However, the composition differs: in the basic diet, cereals, roots, and pulses account for 80% of the calories; and in the affluent diet, these food categories only account for 50%.



**Figure 1.** Differences among the basic and affluent diet. Source: Basic diet: average food supply of Middle African in 2010 [11]; and affluent diet: average food supply of Western Europe in 2010 [11].



### 3.3. Farm Labour for Food

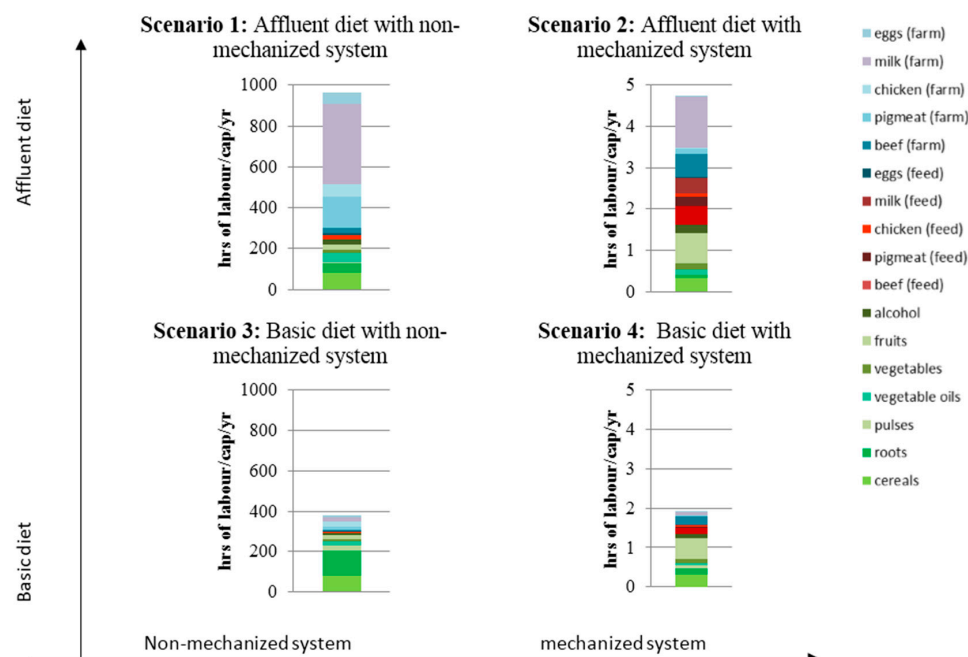
Figure 2 shows the farm labour requirements for food for the four scenarios. The values of this figure represent the time (in hours) of farm labour required to provide for the prevailing dietary patterns; results are broken down into food categories, distinguishing labour required on the livestock farm and on the crop fields producing the feed. The figure shows the strong differences in land requirements among the four scenarios. Scenario 1: 963 hrs/cap/year; scenario 2: 4.7 hrs/cap/year; scenario 3: 375 hrs/cap/year; and scenario 4: 1.9 hrs/cap/year.

The small number of hours needed to produce the food of a person in a mechanized system is striking. Less than five hours of farm labour for an affluent diet and only two hours for a basic diet are needed to produce the food that a person consumes throughout a whole year.

As the difference in the production system has the strongest impact on the farm labour requirements, in the non-mechanized system the picture is very different (note that the scale is 200 times different in scenarios 1 and 3 than in scenario 2 and 4): here, a basic diet requires about 350 hrs to supply a year worth of food supply. The affluent value is higher by a factor of over two compared to this, revealing the impact of dietary patterns.

Not only are the number of hours different among the four scenarios, but also the composition of the hours of labour in relation to the food categories. For basic diets, most of the labour is for the production of the vegetable products: 60% in a mechanized system and 80% in a non-mechanized system. The reason is mainly the low consumption of animal products in comparison with the affluent diet. In contrast, for the affluent diet, less than 30% of the labour is for vegetable products.

Looking in detail to the food categories we have identified the following. The labour for vegetable products produced in non-mechanized systems is more diversified among the different food categories. In contrast, the labour in mechanized systems for the vegetable products is mainly for fruits and cereals. The share of labour for animal products in the total diet is similar for both systems, but the composition differs. In non-mechanized systems (almost) all the labour is on the farm producing the animal products. In the mechanized system, only one fourth to one fifth of the labour is the livestock farms, while the rest is related to the production of feed on different farms.

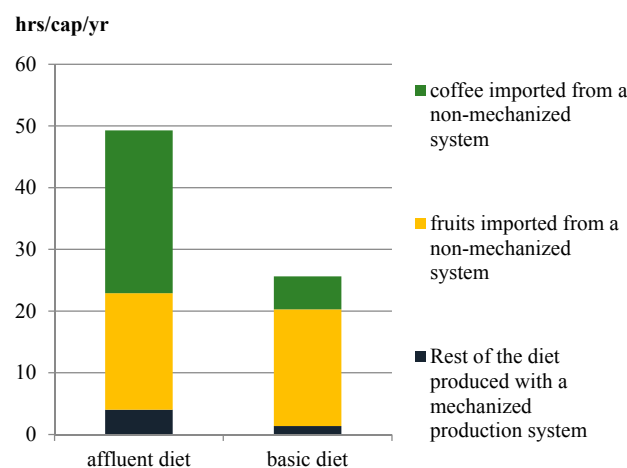


**Figure 2.** Farm labour for food for the four scenarios. See text for details.

### 3.4. Impact of Food Imports on the Farm Labour for Food

The labour required for the production of stimulants, such as coffee, was not included in the analysis. Other studies have shown that the use of resources for stimulants are relevant in relation to the rest of the food categories in the diet [2,3]. The largest per capita consumers of coffee are people living in industrial countries in Northern and Western Europe and North America [11]. These countries import all their coffee consumption [11]. In contrast, the major coffee producers are developing countries, such as Brazil, Vietnam, Indonesia, Colombia, and Ethiopia (according to the average national production data in 2012 [11]). Therefore, the discussion of labour for coffee has to be seen in relation to the impact of food imports. Other affluent food products are also commonly imported by the consuming nations. For instance, Northern Europe imports most of their consumption of fruits (data from 2010 [11]). So, in these cases, the farm labour for fruits and coffee should be discussed in relation to the impact of mixing food products produced with different degrees of mechanization in the overall numbers of farm labour for food consumption.

In Figure 3, we show the calculations of the farm labour for food for an affluent and a basic diet for which all food products are produced in a mechanized system except for fruits and coffee which are imported from a non-mechanized system. For fruits, we used the production data of [8] which was the example of a non-mechanized system for scenarios 1 and 3 (see Table 4 for the production data). For coffee, we used the data of a case study in Indonesia [20] (Table 5).



**Figure 3.** Impact of food imports (coffee and fruits) from a non-mechanized system on the farm labour requirements of otherwise mechanized systems.

**Table 5.** Farm labour requirements for coffee.

Food	hrs/ha	kg/ha	hrs/kg	Basic Diet (hrs/cap/year)	Affluent Diet (hrs/cap/year)
Coffee production in Sumatra Indonesia	1600 <sup>1</sup>	540 <sup>2</sup>	3.0 <sup>3</sup>	5.3 <sup>3</sup>	26.4 <sup>3</sup>

<sup>1</sup> From [20] and we assumed that a working day requires 8 hours of work; <sup>2</sup> average crop yield of Indonesia in 2010 [11]; <sup>3</sup> calculations from the authors.

Bubidarsono et al. [20] calculate the hours of labour needed for several coffee production systems in the Lampung province of Sumatra in Indonesia. Most coffee production systems in this area require around 200 days of work per hectare per year. With this data and the crop yield data [11], we calculated the hours needed per kilogram of coffee produced (see Table 5): 3 hrs/kg. This value is large in comparison with the other vegetable food categories produced in a mechanized system shown in Table 4. As a result, even a low consumption of coffee results in a relatively large need for labour in comparison with the other food categories.

Figure 3 shows the farm labour for food for an affluent and a basic diet produced in a mechanized system, with the exception of coffee and fruits, which are produced in a non-mechanized system. Coffee and fruits imported from a non-mechanized system play a major role in the farm labour for food since it overrules the labour for the other food products produced in a mechanized system. For example, the affluent diet produced with a mechanized system requires 4.7 hrs/cap, but by adding the labour for coffee and fruits from a non-mechanized system, then the whole farm labour for food is as high as 50 hrs/cap.

## 4. Discussion

### 4.1. Main Findings

One of the main insights obtained in this paper is the strong impact of the type of production system due to the labour efficiency gained with mechanization. The farm labour for food with a non-mechanized system is 200 times higher than the one with a mechanized system. The type of diet plays an important role in the farm labour for food, though to a much lesser degree than the production system. An affluent diet requires about two times the number of working hours for a basic diet. This implies that the transition towards affluent diets offsets the reduction of labour requirements due to mechanization only to a very small degree. This finding is different from results for other forms of input into agricultural production, such as land, water, and nitrogen [2,3,5], where the impact of dietary patterns compared to production techniques is much larger.

The mix of the labour hours for different products within the diet differs among the production systems. In non-mechanized systems, the labour in agriculture is more diversified among the food categories, and in mechanized systems it is more concentrated on certain categories, such as fruits. The reason is that labour efficiency for different crop types increases differently with mechanization (see Table 4). The increase in farm labour efficiency with mechanization for cereals, oil crops, and pulses is a factor of about 300; in contrast to vegetables and fruits, the factor is “only” 40–100. These differences are often intrinsic to the crop type, as the possibilities to mechanize farm labour differ greatly depending on the crop. For example, harvesting potatoes requires a lot of labour and mechanization of potato harvest is possible. Thus, farm labour is reduced strongly in mechanized systems. Fruits also require a lot of labour for harvesting but, in contrast with potatoes, full mechanization is more difficult.

The increase in labour efficiency is not only related with mechanization which results in smaller hrs/ha, but also with the increase of crop yields (kg/ha). Some production systems with low mechanization can have relatively high labour efficiency because of high crop yields due to high levels of external inputs, such as fertilizers and pesticides. The impact of differences in crop yields due to yield-related inputs (e.g. fertilizers and irrigation) should be analysed in further research.

### 4.2. Our Results in Perspective

The differences in production systems and diets are related with the socioeconomic development of the population. In general, low income countries have both basic diets [7] and non-mechanized systems [1]. As income increases, diets change to a more affluent consumption [7] and mechanization of production systems increases [1]. In our results, scenario 3 illustrates a low-income country and scenario 2 illustrates a high-income country. The fact that non-mechanized systems in low income countries require more labour than mechanized systems in high income countries is not a novel finding of this paper. The structural transformation theory [21,22] states that, with industrialization, the productivity of human labour increases. With this, the shares of the population in diverse sectors changes from agriculture to manufacturing, and then to services [21]. In relation with this theory, nowadays, the share of the agricultural population in the total population is strongly different between low and high income countries. In low income countries, around 30% of the population is engaged in agriculture, and in high-income countries it is around 1% [22,23]. These values fit with our results if we analyse them as follows: If we consider that a farmer works 2000 hours per year (8 hours a day

and 250 days a year), then with Figure 2 we can say that one farmer with a non-mechanized system can produce the food for five people with basic diets (fit with 30% agricultural population in low income countries); and one farmer with a mechanized system can produce the food for 400 people with affluent diets (fit with 1% of agricultural population in high income countries).

The novelty of our research is to put values of farm hours worked to the food that a person eats in one year. In this way, we put farm labour in perspective to the consumer. Other labour activities related with food consumption are shopping, cooking, eating, cleaning, etc. These activities require many more hours than farm labour, especially for developed countries. Let us assume that 2 hours per person per day are needed for these activities, giving us 730 hours per year per person. Then, the labour for these activities is 150 times higher than the farm labour for developed countries (mechanized and affluent diet), and two times higher for developing countries (non-mechanized and basic diets). These differences among the agricultural resource (farm labour) and the consumer (household's labour for food) is different for other agricultural resources such as land and water use. The cropland needed to produce the food of one person is around 2000 m<sup>2</sup> per year, for the global average [2], which is much more than the land that the person needs for living (a house or apartment). The water needed to produce the food of one person is 1.3 million litres per person per year [3], which is much more than the per capita household's water supply: 50 thousand litres per year [3], or the per capita drinking water: 730 litres per year (two litres per person per day).

Nowadays, global agriculture is strongly dependent on energy from fossil fuels [24], which has a large impact on climate change. An important trade-off between extensive and intensive system is the energy use including not only fuel for machinery but also yield related inputs, such as fertilizers, irrigation, and pesticides [9]. Pimentel shows that the energy use for intensive systems is two times higher than the energy use for extensive systems [9]. Pimentel calculates the energy input related with all agricultural inputs for several systems [9]. Based on these results, we calculate that two times more energy is needed for intensive than extensive system by comparing the following systems of Pimentel: (1) maize production in Indonesia (extensive) and the USA (intensive); (2) wheat production in Kenya (extensive) and the USA (intensive); rice production in India (extensive) and the USA (intensive); and cassava production in Nigeria (extensive) and potato production in the USA (intensive). Thus, "energy savings" of extensive systems, in comparison with intensive systems, is two times. However, with our results we can say that "labour saving" related with this intensification is 200 times. So, the trade-off between energy and labour in relation to agricultural intensification is 100 times. This gives new insights to design options to reduce energy use in agriculture since, at a farm level, energy reductions will require large increases in labour which might not be easily implemented. Other studies have shown that strategies to reduce environmental impacts that require more labour are unlikely to be implemented (e.g., the implementation of biogas production with agricultural wastes in rural Ethiopia [25]).

#### 4.3. Limitations of Our Methodology

In this paper, we analysed two production systems which are strongly different to each other. In reality, production systems vary throughout the world, so by choosing other production systems or other assumptions for the production data, the values of Figure 2 could differ. However, the general patterns are robust as the sensitivity analysis in Supplementary Materials indicates. Our aim is to illustrate global differences and discuss orders of magnitude. Therefore, our values should not be considered as exact values, but as a starting point to discuss the impacts of production systems and diets on agricultural labour requirements. In addition, we only considered the labour needed for food production up to the farm gate. The rest of the food chain also requires labour for transport, food processing, storage, cooking, etc. This is outside the boundaries of our research.

It is important to note that the aim of our study was to investigate the effect of mechanization and diet on the required working hours in agricultural fields. This way we address the question of how ongoing transition processes transform the need for traditional on-farm labour. Part of the reduced

labour input will be offset by additional off-farm labour for e.g. producing machines or agribusiness retail work. Here, comprehensive LCA studies with wider system boundaries or approaches using economic input-output models [26,27] are more suited to assess trade-offs between on-farm and off-farm labour requirements for food production.

The farm labour for food (Figure 2) gives an indication of the number of people that a farmer can feed in the four scenarios that were studied. Assuming that a farmer works 2000 hrs/year (8 hours a day for 250 days), then the farmer with a mechanized system can produce the food for 400 people with affluent diets (scenario 2) and 1000 people with basic diets (scenario 4), and with a non-mechanized system the farmer can produce the food for five people with basic diets (scenario 3), and only two people with affluent diets (scenario 1).

## 5. Conclusions

Our study provides insights on the impact of diets and production systems on the need for agricultural labour. The increase of labour efficiency with mechanization is enormous, greatly reducing the amount of farm labour requirements to feed an average person. The impact of dietary patterns on farm labour requirements is also relevant, but not comparable with the effect of mechanisation. With a mechanized system, less than 5 hours of farm labour are needed to produce the food consumed by a person during a whole year with an affluent diet. This value is much lower than the time an average person spends on buying food, cooking, or eating.

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